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DESIGN FACTORS AFFECTING THE STRENGTH AND RIGIDITY OF WOODEN CRATES

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INTRODUCTION

Five billion board feet of lumber, ultimately paid for by the consumer, go into boxes and crates each year. It is therefore clear that the manufacturer of more efficient wooden crates will not only help reduce the cost of commodities but will also be reflected in the more efficient utilization of the wood of our forests.

In the past, when high-grade lumber was relatively cheap and plentiful, no special concern was felt by manufacturers and shippers about the design of their crates, since with a generous use of lumber and nails it was not difficult to make a crate that would get the product to its destination without serious damage. At that time, however, the competition in industry was not so keen and commodities were distributed over a much smaller territory than they are to-day. Consequently, the extra cost of lumber, the added freight due to extra-heavy crates, and the high damage claims caused from improper design, although excessive as compared with present-day standards, were considered necessary evils and not worthy of special attention. Considering the close competition that exists to-day between the various industries as well as the diminished supply and higher cost of high-grade lumber, it is apparent that any small saving in the packing end of an industry through the reduction in the amount or through the lowering of the grade of lumber used in crating may mean the difference between a profit and a loss on a given commodity.

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[1] Acknowledgment is made to J. A. Newlin, in charge of section of timber mechanics of the Forest Products Laboratory, for assistance in the preparation of this circular.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

PURPOSE

The Forests Products Laboratory, in investigations of the fundamental principles of design of shipping containers that are economical in the use of lumber, has studied numerous factors involved in efficient crate design. The purpose of this publication is to show the effect of various design details on the strength and rigidity of wooden crates.

DESCRIPTION OF MATERIAL

Clear, straight-grained ponderosa pine, western hemlock, and Sitka spruce in a thoroughly dried condition (8 to 15 per cent moisture content) were used in the construction of the test crates. It is not good utilization to use clear lumber for crates. In any series of tests, however, it becomes necessary to eliminate all but one factor at a time in order to determine the true influence of that factor on strength. Consequently, by eliminating defects and other variables, it becomes possible to study a single design factor without danger of complicating the results.

All the crates tested were of 3-way corner construction. (Fig. 1.)

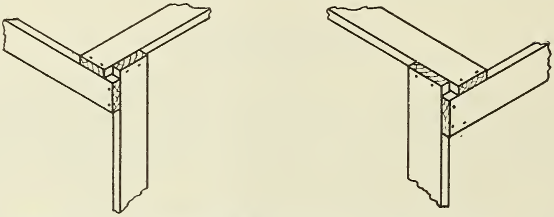

FIGURE 1.—Arrangements of the 3-way corner used in the test crates

Five shapes of crates, varying from relatively flat to cubical, were tested. The number, species, dimensions, and displacements of crates tested are given in Table 1. Each shape of crate is designated by the reference letters given in column 1 of Table 1. The exact dimensions and displacements of the crates varied slightly in some instances from those given in Table 1 because of the method of attaching braces and edge members.

TABLE 1.—*Specifications of the test crates*

Shape	Crates tested	Species	Outside dimensions (inches)	Displacement
	Number			*Cubic feet*
A	105	Ponderosa pine	24¼ by 16½ by 10½	2.4
B	300	do	20 by 15 by 14	2.4
B	114	Western hemlock	20 by 15 by 14	2.4
C	20	Sitka spruce	24 by 24 by 24	8.0
D	2	Ponderosa pine	36½ by 28½ by 21½	12.9
E	21	Sitka spruce	30 by 30 by 30	15.6

MATCHING AND MARKING

The A and B crates were constructed in lots of three; the C, D, and E crates in lots of two. The crates in each lot were made at the same time of the same size and design, and of the same width, thickness, and quality of material. They were also tested at the same time and in the same manner. Each crate in a lot had the same lot number. In order to eliminate as far as possible the influence of the variability of clear wood, corresponding members in the crates of each lot were made from the same board. In most instances the lots were matched in the same manner.

NAILING

In general, unless the nailing was the factor being studied, all crates were nailed approximately in accordance with the nailing given in Table 2.

TABLE 2.—*Nailing used for the test crates*

Thickness of members (inches)	Size of nail in—		
	Ponderosa pine	Western hemlock	Sitka spruce
	Penny	*Penny*	*Penny*
3/8	4	4	--------
9/16	7	6	6
3/4	9	7	--------
1 1/4	9	7	--------

METHOD OF TESTING

The diagonal-compression test (fig. 2) was employed in this study.[3] Pressure was applied by means of a testing machine to diagonally opposite corners of each crate at the rate of one-fourth inch per minute. In testing, the loads corresponding to equal increments of deformation on a telescopic tube placed diagonally between the loaded corners were recorded. The diagonal distortion measurement so obtained represented quite well the comparative rigidities of the various crates. In addition, the diagonal distortion and the twisting in the individual faces were measured for the cubical crates. A determination of the moisture content of the wood in each crate was made immediately after test on a section about 2 inches long cut from one edge member, usually the edge member in which failure occurred.

DISCUSSION

In the following discussion, the principal comparisons are based on the maximum load attained up to 1-inch diagonal distortion of the crate. In most instances this was the load at 1-inch distortion, but in some very rigid crates the maximum load was attained before 1-inch distortion was reached. The lot averages are obtained by averaging the maximum loads obtained up to 1-inch distortion for the individual crates comprising the lot. The advantage of using this average rather than the average maximum load is that it affords a rough measure of rigidity. A crate may sustain a high maximum load, but the load may be at a relatively large diagonal distortion. Crates for furniture and similar commodities normally give little protection to their contents after 1-inch diagonal distortion has been exceeded.

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[3] A complete description of the diagonal-compression test appears in the following publication: PLASKETT, C. A. PRINCIPLES OF BOX AND CRATE CONSTRUCTION. U. S. Dept. Agr. Tech. Bul. 171, 134 p., illus., 1930.

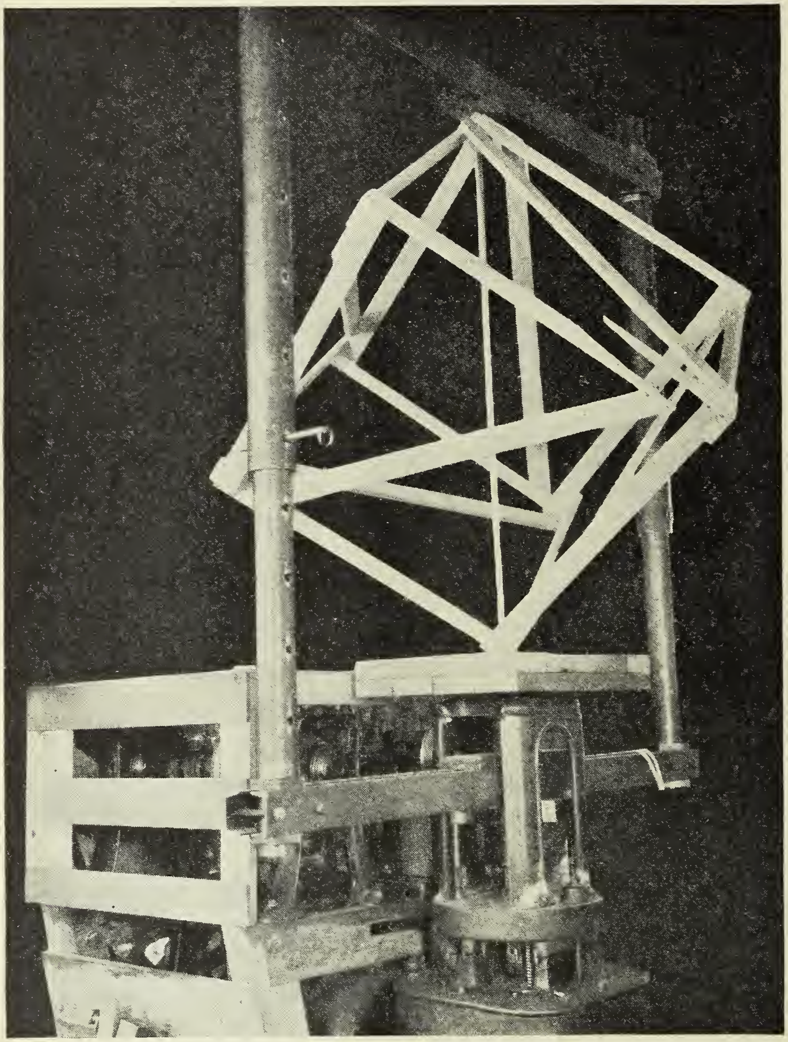

FIGURE 2.—The diagonal-compression test

CHARACTERISTIC FAILURES IN CRATES AND STRESSES CAUSING THEM

Observations of failures in diagonally braced crates made of lumber free from injurious defects show that the critical point of failure is usually at the fastening of the diagonals to the edge members. Failure may occur because the nails pull, because the diagonals shear from the nails, or because the edge members split at the point where the nails fasten the braces. The type of failure will depend on the relation between such factors as width and thickness of material; size and shape of crate; workmanship in manufacture; size, type, and number of nails; and species of wood.

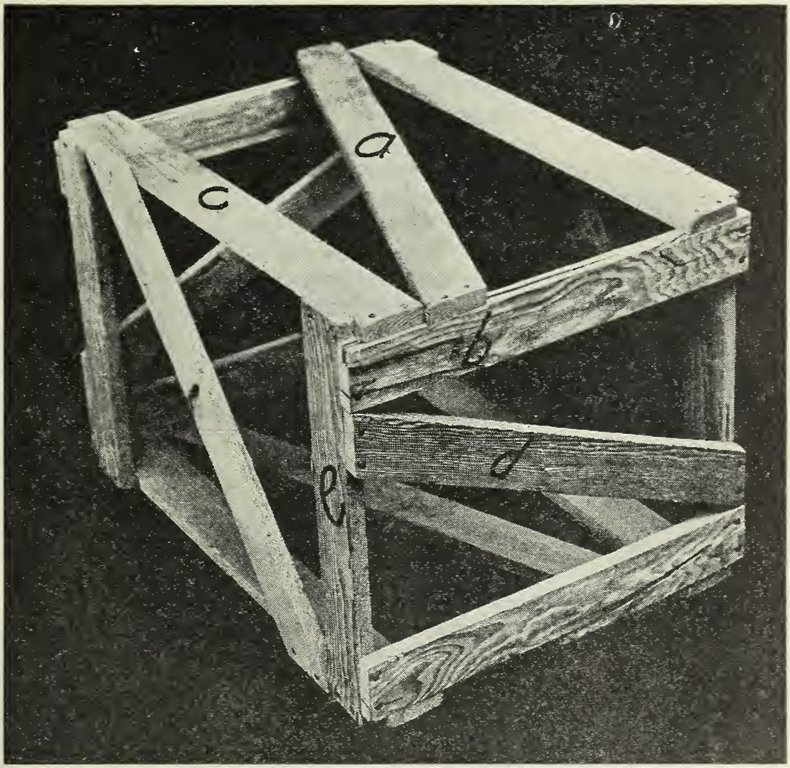

FIGURE 3.—Characteristic failure caused by splitting at the fastening of the diagonal brace *a* to the edge member *b*. This point of fastening is the one which receives the maximum stress. The stress causing the split at *b* is the component of the stress in brace *a* that acts perpendicularly to *b* at the nails. This component is proportional to the length of *c*, one of the longest edge members. No failure occurred at the fastening of the brace *d* to the edge member *e*

An analysis of the stresses in crate members (fig. 3) and observation of the failures occurring in crates under diagonal-compression tests show that failures in fully braced crates under normal handling will nearly always occur at the fastening of a diagonal brace having the maximum stress component perpendicular to the edge members to which it is fastened. The analysis further shows that the forces in the various faces tending to cause the splitting of the edge members (fig. 3) to which the diagonal braces are nailed are approximately proportional to the lengths of the edge members to which the braces are not nailed. This relationship affords a very convenient and practical means of quickly locating the most likely point of failure in any crate having diagonal braces on all faces, regardless of whether the braces are nailed to the narrow or to the wide faces of the edge members.

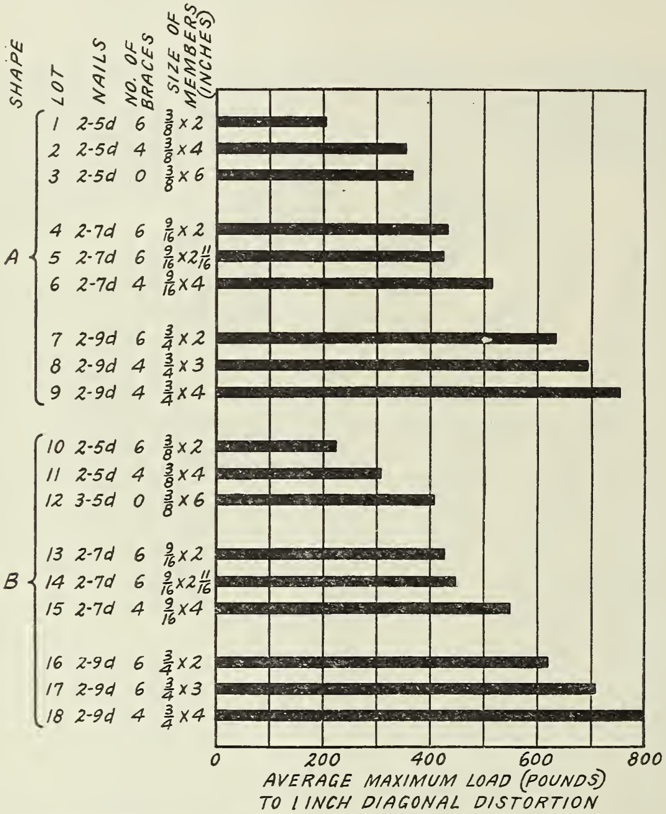

FIGURE 4.—Effect of increase in width of members on strength of crates

Other things being equal, a long edge member will fail more readily by splitting at the fastening of the diagonal braces than a short edge member when the braces are nailed to their edges. (P. 9.)

RELATION BETWEEN WIDTH AND THICKNESS OF CRATE MEMBERS

Figures 4 and 5 show graphically the results of tests on the two sizes of crates (A and B, Table 1) in which the width and thickness of the crate members were varied. The figures compare crates with members three-eighths, nine-sixteenths, and three-fourths inch thick and from 2 to 6 inches wide. The percentage increase in strength caused by increase in thickness of the crate members is more rapid than the percentage increase in amount of material used. Practically all the crates showed some increase in strength with increase in width of crate members, but the percentage increase was much less rapid than the percentage increase in amount of material in the crates.

The effect of width of braces was studied in a few of the crates in which the braces were fastened to the wide faces of the edge members. (Fig. 6.) For the same nailing in lots comparing 2 and 4 inch wide braces, no great difference was found. In other words, except for the greater coverage by the 4-inch braces, no advantage was gained from using the wide braces. This is because the strength

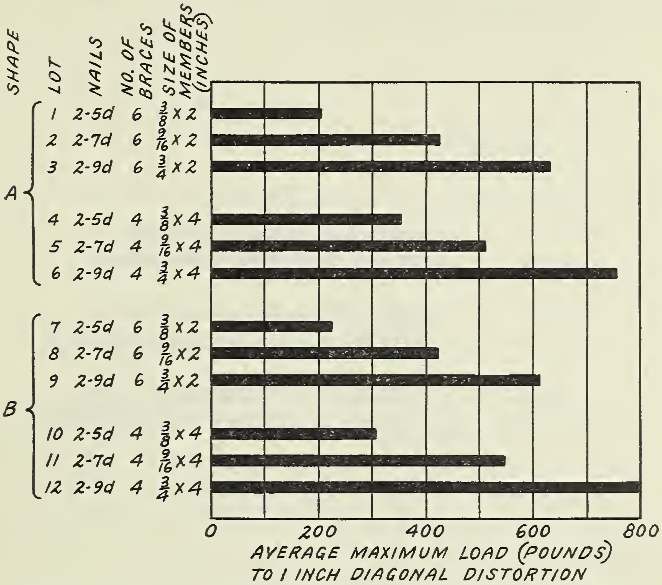

FIGURE 5.—Effect of increase in thickness of members on strength of crates

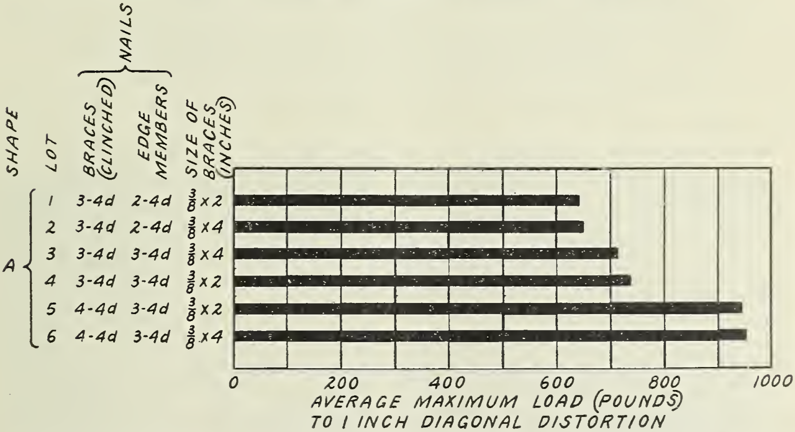

FIGURE 6.—Comparison of crates having 2-inch wide braces with crates having 4-inch wide braces when same thickness of material and nailing are used in each. Tests made on ponderosa pine crates having edge members ⅜ by 4 inches in size. One brace in each face, nailed to the wide faces of the edge members

of the crates was limited in both cases by the holding power of the nails fastening the braces to the edge members.

As a general principle, for crates with members of the same cross-sectional area, of the same species, and nailed in accordance with the nailing schedule recommended on page —, the strength will increase as the members approach a square cross section. This is illustrated by tests of crates of western hemlock (fig. 7, lots 1 to 4) and ponderosa pine (fig. 7, lots 5 and 6).

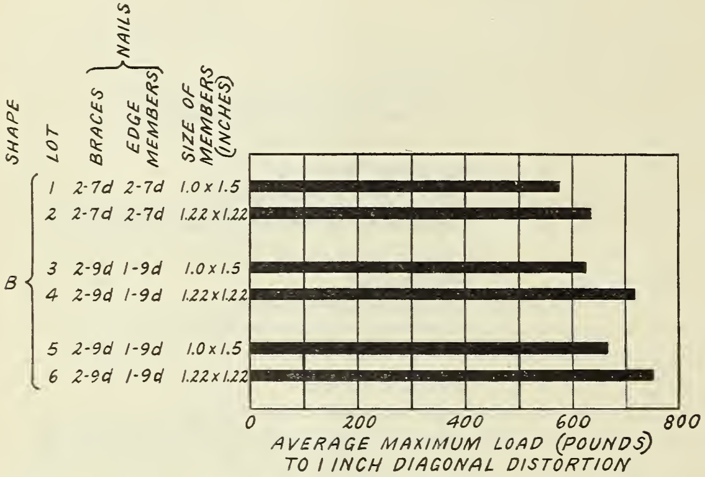

FIGURE 7.—Effect on strength of varying the width and thickness of crate members. Tests made on ponderosa pine and western hemlock crates having all faces braced

Although square members make the strongest crates for a given cross-sectional area of the members, there are practical considerations, such as reduced coverage and increased difficulty in nailing, that generally require rectangular members, but the nearer such members approach a square in cross section the greater will be their strength.

Data were also obtained on crates having six diagonally braced faces in which the diagonals were one-half the thickness of the edge members. These data, which are given in Figure 8, show that crates having braces the same width but one-half the thickness of 3/8, $\frac{9}{16}$, and 3/4 inch edge members, respectively, are nearly as strong and rigid on an average as crates having braces of the same thicknesses and width as the edge members. This is due to the fact that with diagonal braces of the same thickness as edge members, failure is almost always the result of the edge members splitting at the nails fastening the braces. With the thinner diagonal braces, the edge members still failed in a large number of instances by splitting in the same manner as with the thicker braces, but occasionally the diagonals sheared from the nails. In reducing the thickness of braces, due regard must be given the ratio between their length and thickness. If this ratio exceeds $\frac{60}{1}$ the braces are apt to buckle under compressive stress and the result is relatively low strength for the crate. This weakness can be overcome by the use of two braces crossed in each face. (P. 17.)

EFFECT OF MANNER OF ASSEMBLING EDGE MEMBERS

There are two common arrangements whereby the edge members can be assembled in a 3-way corner crate. One of these, referred to as arrangement No. 1 (fig. 9, A), has the long edge members nailed to the short edge members in the smallest faces. The other, referred to as arrangement No. 2 (fig. 9, B), has the short edge members nailed to the long edge members in the smallest faces. Tests of 3-way corner crates with no two dimensions alike, indicate that arrangement No. 2 has slightly higher strength and rigidity

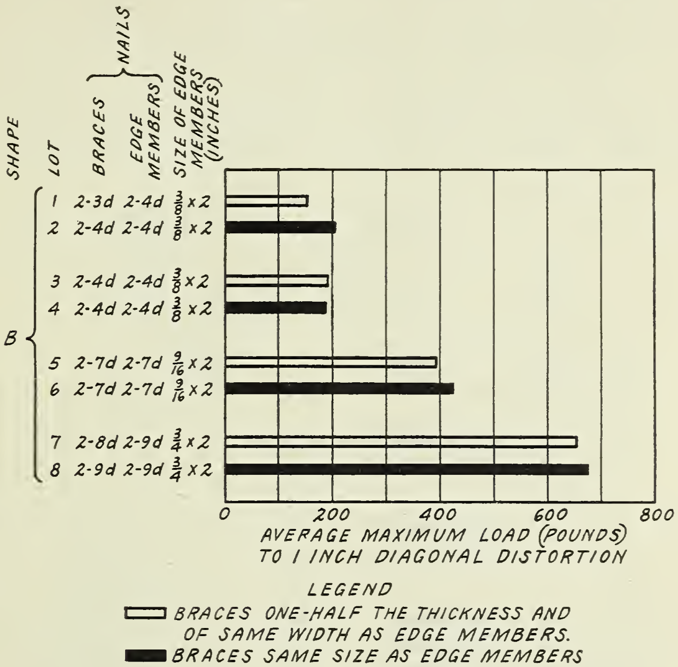

FIGURE 8.—Crates having six diagonal braces one-half the thickness of the edge members are nearly as strong and rigid on an average as crates having braces of the same size as the edge member

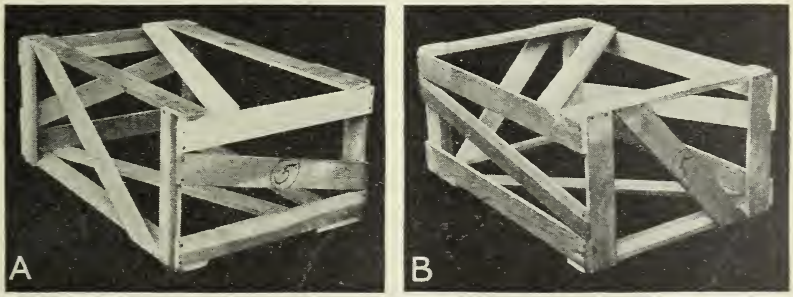

FIGURE 9.—Two common arrangements of edge members in 3-way corner crates: A, Arrangement No. 1; B, arrangement No. 2

than arrangement No. 1. (Fig. 10.) The difference between the two arrangements, however, is relatively small, and the controlling factor should be convenience and protection of the face of the commodity rather than increase in strength of the crate through rearrangement of the edge members.

EFFECT OF ARRANGEMENT OF DIAGONAL BRACES IN FULLY BRACED CRATES

Tests on fully braced crates showed no significant effect on the strength and rigidity resulting from varying the relative positions of the diagonals. (Fig. 10, lots 5 to 8.) If a diagonal brace comes to a loaded corner, it is in compression; if not, it is in tension. These crates had braces so arranged that under diagonal compression lot 5 had 3 braces in compression and 3 in tension, that is, the braces in opposite faces were crossed; lot 6 had all braces in compression; lot 7 had 2 braces in compression and 4 in tension; and lot 8 had all braces in tension. If any difference exists due to the kind of stress in the diagonals, it should show in lots 6 and 8 in which there was a complete reversal of stress in the diagonals. The results, however, indicate so small a difference as to be practically negligible. With the exception of the crates studied for effect of arrangement of braces (fig. 10, lots 6 to 8), all the crates with 6 braces were constructed with the single braces in opposite faces crossed. With this arrangement of the braces, there is always one of each pair of opposite braces in tension and one in compression when a crate is loaded on diagonally opposite corners.

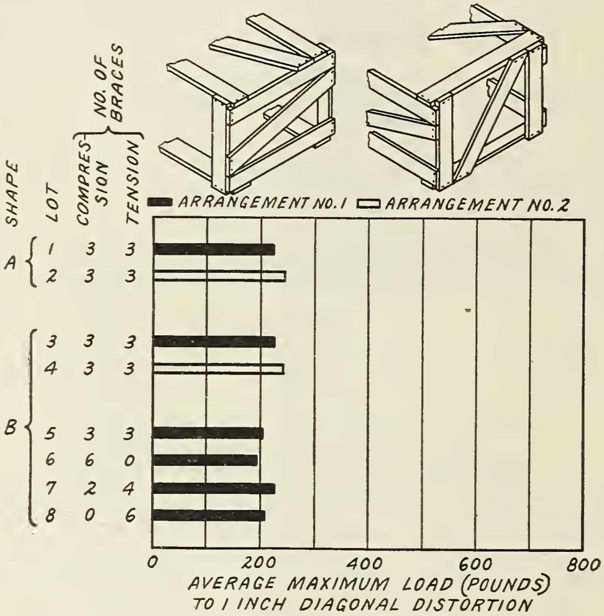

FIGURE 10.—Effect of arrangement of members on strength. All crates had six diagonals and ⅜ by 2 inch edge members, and were nailed with two 4-penny nails at each end

EFFECT OF NUMBER AND RELATIVE POSITIONS OF BRACED FACES

If an empty crate has five faces braced diagonally and is loaded on diagonally opposite corners or in any way to give diagonal distortion in the unbraced face, then all faces will twist as shown in Figure 11. However, should one of these faces be able to resist twisting, then all the faces will remain free from twist. This means that if a commodity is packed in a crate with five faces braced and fastened rigidly to one of the braced faces, then twisting will occur in the commodity whenever the unbraced face is distorted diagonally. A piece of furniture packed in such a crate and subjected to rough handling is apt to be racked in the joints or come into injurious contact with the crate, although the crate when examined at its destination is in apparently perfect condition. This type of damage caused in shipment is often erroneously attributed to the use of improperly seasoned lumber in the commodity.

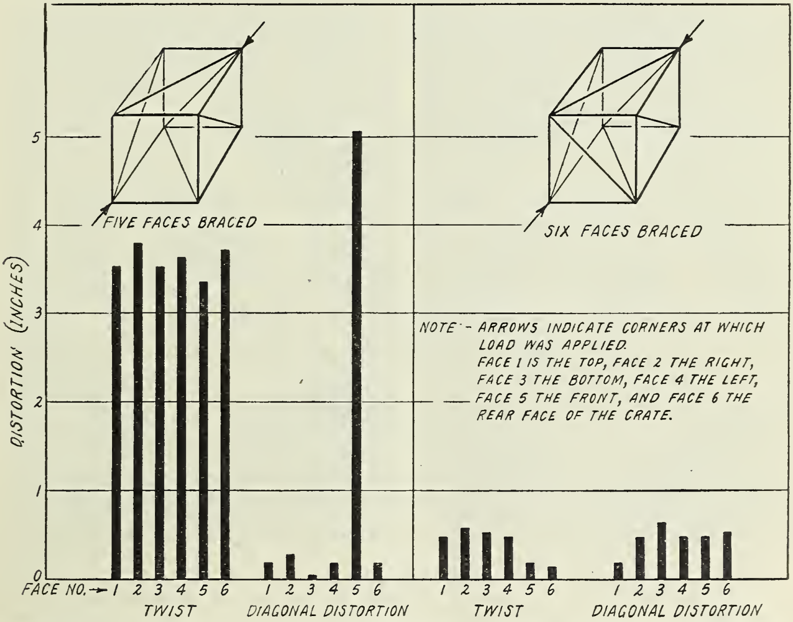

FIGURE 11.—Average amount of twisting and diagonal distortion in individual faces of crates with five and six braces at maximum load in diagonal-compression test

When a commodity having relatively thin plates or walls in one or more of its faces is subjected to torsional stresses, these thin walls will buckle. If the walls are of such material as sheet iron with a baked-enamel finish, the buckling has a decided harmful effect, since the enamel cracks and flakes off. Unfortunately the cause of the cracked enamel is not apparent, since the crate under such conditions shows no evidence of having been racked out of shape, and as a result, the blame is frequently laid to poor manufacture of the commodity. When all of the crate faces are braced and the commodity properly supported, racking of the contents can not take place until failure in the crate has occurred.

If the commodity is rigid and able to withstand all of the twisting that may normally occur, then one and sometimes two faces may be left unbraced, but such a crate is considerably weaker than a fully braced crate. For example, if a gas engine with a heavy base is bolted to one face of a crate, then this face and any other face may be left unbraced, since the rigid base of the gas engine can usually resist whatever distortion or twisting would normally occur.

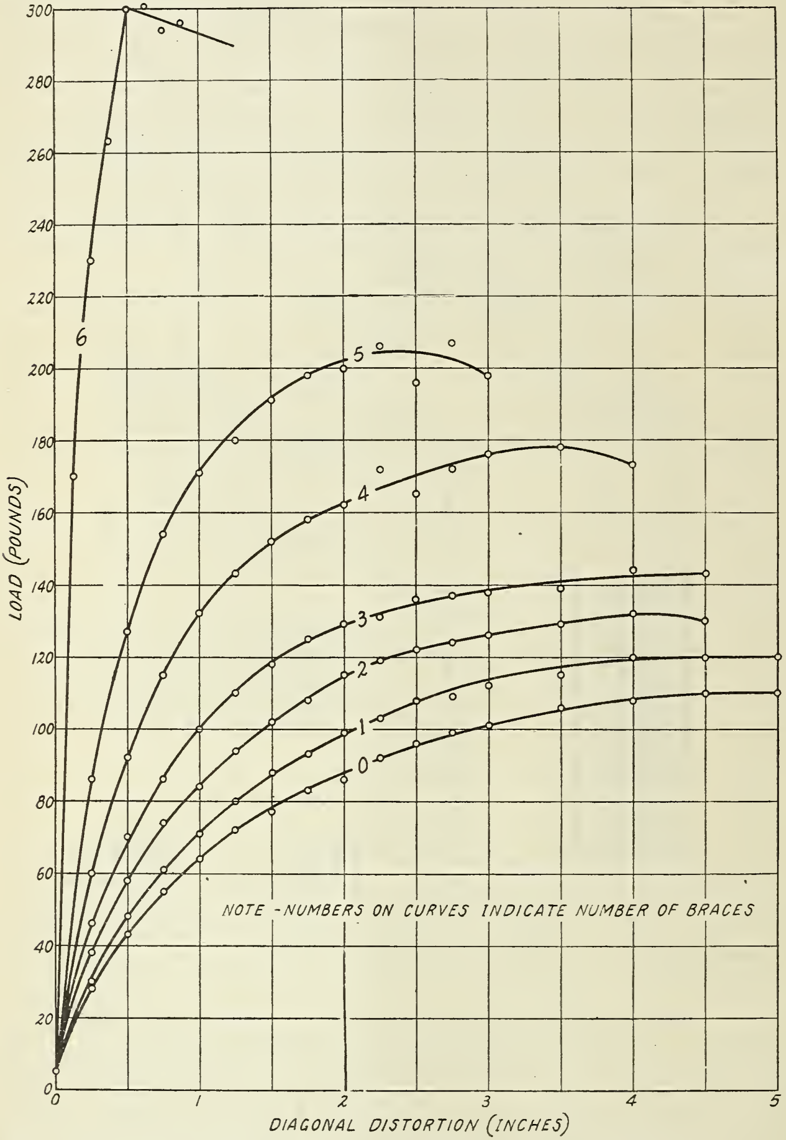

FIGURE 12.—Comparative rigidities of crates tested in diagonal compression and having various numbers of braces

Figure 11 shows that the maximum resistance to diagonal distortion is obtained where all six faces of a crate are braced diagonally. The small diagonal distortions and twisting in the individual faces of crates with six braces that occur despite the braces are a result of stresses at maximum load when considerable slipping has taken place in some of the joints. It is evident from Figure 12 that as the number of braces is increased the resistance of crates to diagonal distortion is also increased. For example, at a diagonal distortion of one-half inch, crates with 1, 2, and 3 braces carried about 10, 35, and 60 per cent greater load than the crates with no braces. Crates with four braces carried more than twice the load; crates with 5 braces carried about three times the load; and crates with 6 braces about seven times the load that the unbraced crates carried at ½-inch diagonal distortion.

If the commodity is nonrigid and unable to withstand all the twisting that would normally occur, then all faces should be braced, or the commodity must be fastened in the crate in such a way as not to be distorted by distortion of the crate. Figure 13, A, which was photographed after a diagonal-compression test, shows a fully braced crate with a plaster of Paris panel securely fastened to one face. The crate withstood a maximum load of 680 pounds at 1¼ inches deformation along an interior diagonal without enough twisting to crack the panel or to be discernible without careful measurement. At maximum load one of the long-end edge members split at the nails fastening the diagonal brace to it. The load was immediately removed before sufficient deformation took place to cause failure of the panel. A second test was then made on a crate with five faces braced and the panel fastened to one of the braced faces. Figure

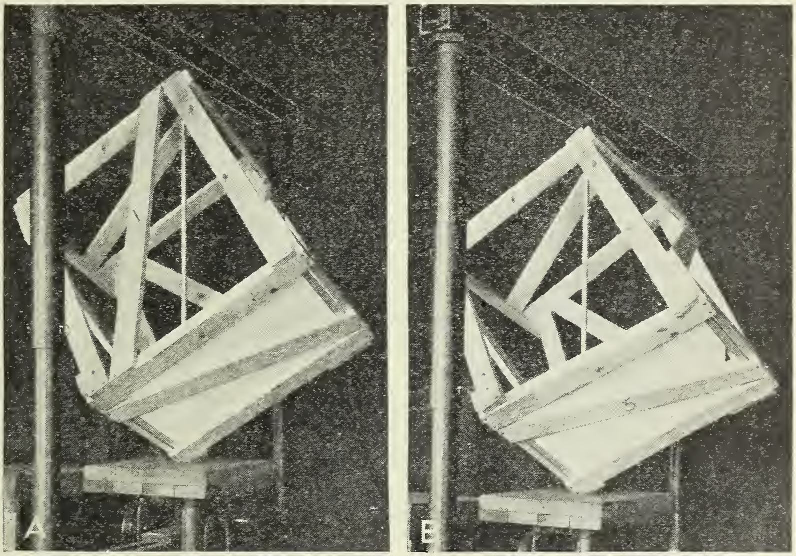

FIGURE 13.—A.—Diagonal-compression test of a fully braced crate having a plaster of Paris panel attached to one face. No twisting or injury to the panel resulted at a maximum load of 680 pounds and a deformation of 1¼ inches. B.—Diagonal-compression test of a crate with five braces having a plaster of Paris panel attached to one braced face. The panel cracked as the result of the twisting of the crate at a load of 390 pounds and a deformation of 1½ inches

13, B, shows this crate after test. The first crack in the panel occurred at a load of 390 pounds and a corresponding deformation of 1½ inches. The twisting in the faces can be seen. When the external force was removed the crate returned to its original shape with no visible signs of having been stressed except the broken plaster of Paris panel. The diagonal distortion which occurred in the unbraced face was accompanied by twisting in all faces. Observation and tests have demonstrated that under these circumstances twisting and distortion in the unbraced face occurs no matter how the crate is handled.

The effect on strength of varying the relative positions of the braced faces with respect to each other is shown by the tests on crates having 2, 3, and 4 braces. (Fig. 14.) The curves in each of the three sections of the chart shows practically no difference in strength and rigidity due to arrangement of the braced faces. For example, in Figure 14, A, curve *a*, for crates with two opposite faces braced, falls very close to curve *b*, representing crates with two adjacent faces braced. Likewise, in Figure 14, C, curve *a*, for four faces braced with the unbraced faces adjacent, differs but little from curve *b*, which is for crates with two pairs of opposite faces braced. Practically equal diagonal distortions in the two adjacent unbraced faces resulted in nearly the same amount of twisting in the top and bottom faces of the crates plotted in curve *a*. No twisting occurred in the four other faces. In Figure 14, B, the crates represented by curve *a* had three braces in compression, those represented by curve *c* three braces in tension, and those represented by curves *b* and *d* two braces in compression and one in tension but with different arrangements. Here again no significant difference in strength was obtained for the different arrangement of the braced faces. Figure 14, B, also shows that the type of stress in the braces, that is, whether tension or compression, had no appreciable effect on strength and rigidity. That is, of course, contingent on the braces being thick enough to resist normal compressive stresses without bending. It was noted, however, that twisting occurred in all the crates with three braces irrespective of arrangement.

A study of the effect of the number of braces on the twisting tendencies of the crates when subjected to the diagonal-compression test showed further that any odd number of braces, that is, 1, 3, or 5; or an even number unsymmetrically disposed, always caused twisting. (Fig. 15.) An even number of braces did not cause twisting provided the braced faces were symmetrically arranged in the crate. Unbraced crates distorted about equally in all faces under stress and therefore did not twist. The foregoing statements, however, will not always hold for all kinds of handling.

The effect of varying the number (up to six) and relative positions of the diagonals as determined from diagonal compression tests on the cubical crates may be summed up as follows:

If a crate is constructed and handled so as to cause twisting in one face, then the opposite face will also twist and by the same amount.

If opposite faces distort diagonally unequal amounts or in opposite directions, twisting will always be produced.

If opposite faces distort diagonally by the same amount and in the same direction, no twisting is caused from this distortion.

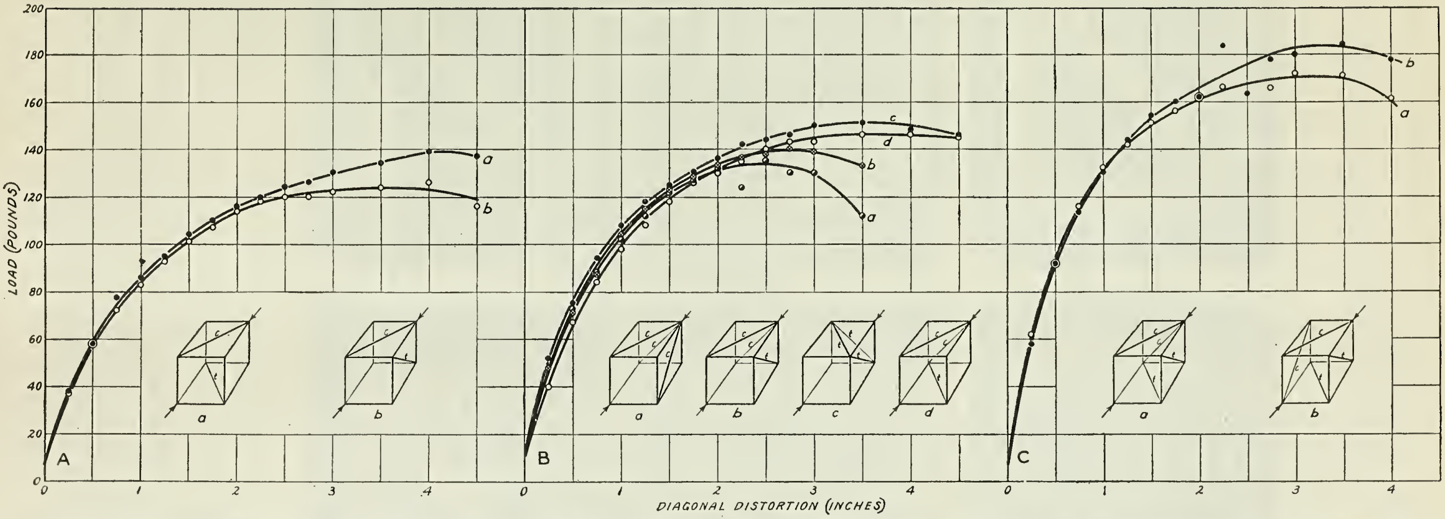

FIGURE 14.——Comparison of rigidities of crates with various numbers of braces showing the effect of varying the relative positions of the braced faces. The braces marked *c* were in compression and those marked *t* were in tension: A. Crates with two faces, braced; B, crates with three gaces braced; C, crates with four braces braced

If one face of a crate distorts diagonally without any of the others distorting, all faces will twist.

If two adjacent faces of a cubical crate distort diagonally unequal amounts and no diagonal distortion takes place in the other faces, twisting will occur in all faces.

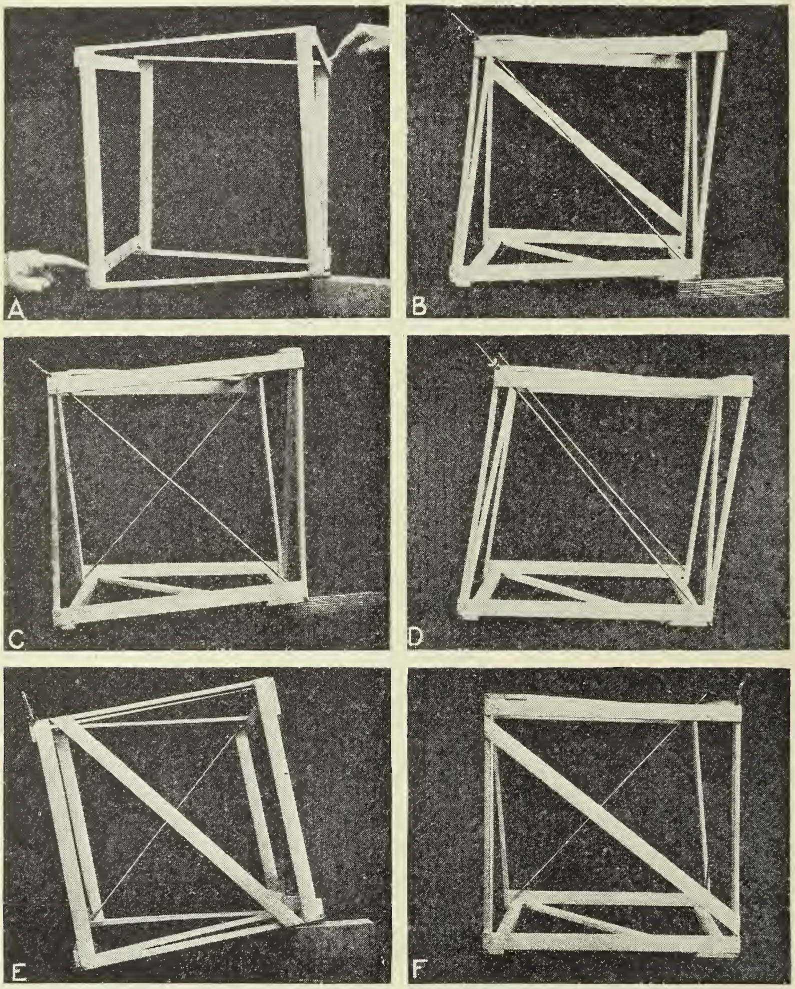

FIGURE 15.—Model crates used for demonstrationg the cause of twisting in crates: A, Unbraced crate stressed to show twisting in all faces; B, crate with five faces braced, showing how twisting occurs when unbraced face is diagonally distorted by means of a wing nut and threaded rod; C, crate with two opposite faces unbraced shows twisting in all faces when the two unbraced faces are distorted in opposite directions; D, crate with two opposite faces unbraced, showing no twisting when the two unbraced faces are distorted in the same direction by equal amounts; E, crate with four faces braced, showing how top and bottom faces twist when two adjacent unbraced faces are distorted diagonally so that the diagonals which lengthen meet at the same corner between the unbraced faces; F, crate with four faces braced and two adjacent faces unbraced, showing how the two adjacent faces and their opposite faces twist when distortion in the two unbraced faces is such that the two diagonals lengthening do not meet at a corner; there is no twisting in top and bottom faces

No general rule can be stated regarding the twisting in crates having zero to four braces, inclusive, under all conditions, since the stresses are dependent on the packing and method of handling.

Whether braces are in compression or tension makes no difference provided the braces are thick enough to take compressive stress without bending.

For a given number of braced faces, there appears to be no appreciable difference in the maximum load and total distortion due to the arrangement of the braces.

The strength and rigidity of a crate increases with each diagonal brace added, the maximum increase occurring with the addition of the sixth brace.

CROSS BRACES

The discussion thus far has dealt only with crates having up to six diagonal braces heavy enough to resist compressive stress without buckling. Relatively thin braces are apt to buckle under compressive stress at appreciably lower loads than relatively thick braces. Buckling of very thin braces can, of course, be prevented in crates with six braces if all are in tension, but this is impractical since dropping the crate on the various corners reverses the stresses in the diagonals. The most practical way to provide proper rigidity and strength in crates with relatively thin braces under all conditions of handling is to use two thin braces crossed in each face. (Fig. 16, C and D.) On an average this construction resulted in about 50 per cent higher strength for crates with 12 braces one-half the thickness of the edge members than for crates with 6 braces the same thickness as the edge members. (Fig. 17.)

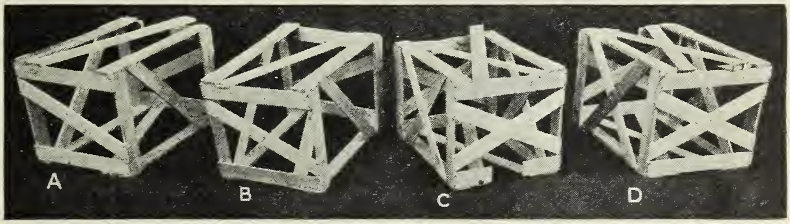

FIGURE 16.—Crates tested to determine the relative efficiency of single and double braces on six faces: A, 6 braces of the same thickness as the edge members; B, 6 braces one-half the thickness of the edge members; C, 12 braces one-half the thickness of the edge members; D, 12 braces one-half the thickness of the edge members and nailed at intersection. Constructions C and D were about 50 per cent stronger than the A and B constructions. Construction B had about the same strength as A. D was slightly more efficient than C, especially in crates with relatively thin braces. The samples used for the determination of the moisture content of the crate material immediately after test were taken from the rectangular cuts shown on the various members

With crossed bracing one brace is in tension and one is in compression in each face under any kind of loading. Both take increasing stresses with increasing load until the compression brace starts to buckle, after which the major stress is thrown into the tension brace. In general the tests showed slightly greater strength when the compression braces were inside the tension braces than when outside; however, when the crate is loaded on different corners the stresses in the diagonals are likely to be reversed; consequently it is impossible to determine which brace will be in compression. Nailing the braces at their intersection, however, accomplishes the same results regardless of the relative positions of the braces. (Fig. 18.)

Where two crossed braces are used in each face, it is often practicable to nail one brace to the narrow faces of one pair of edge members and one to the wide faces of the other pair of edge members in the crate face. (Fig. 19, C and D.) Figure 17, lots 3 and 4, shows that crates so constructed with braces one-half the thickness of the edge members have about double the strength of crates with one brace in each face the same thickness as the edge members nailed to the narrow faces of the edge members. This crossed-brace construction gives a strength somewhat greater than for crates with two crossed braces in each face, both nailed to the narrow faces of the edge members (fig. 17, lot 2), and somewhat less than for crates having one brace in each face (fig. 19, B) nailed to the wide faces of the edge members. (Fig. 20, lots 2 and 4.)

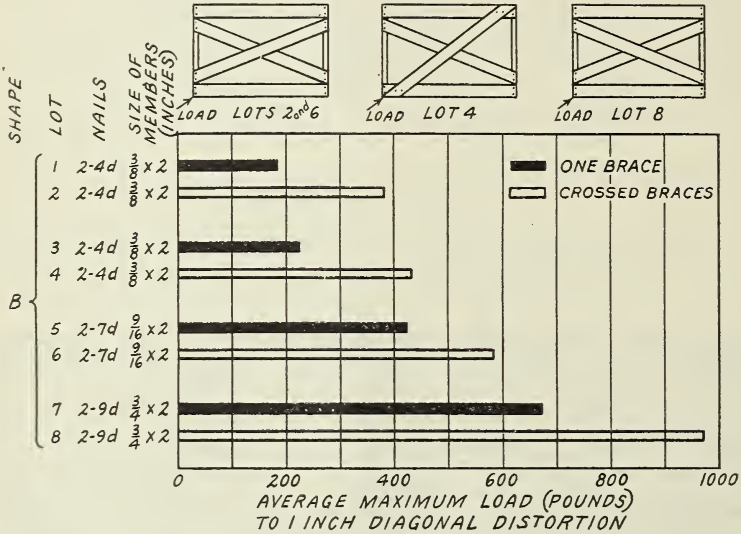

FIGURE 17.—Crates having crossed braces one-half the thickness of the edge members in each face compared in strength with crates having one brace in each face of the same thickness as the edge members. Lots 2 and 6 had the compression brace outside the tension brace in each face. Lot 4 had the compression brace inside the tension brace in three faces and outside in three faces with one brace in each face nailed to the edge of the edge members and one nailed to the wide face of the edge members. Lot 8 had the compression brace inside the tension brace in each face

In summing up, it appears that the direction of the diagonals in the various faces of crates with six diagonal braces has very little influence on strength so long as the diagonals are stiff enough to resist compressive stress without appreciable bending. It is also evident from the data that crates with two braces one-half the thickness of the edge members crossed on each face have 1⅓ to 2 times the strength of crates with only one brace the same thickness as the edge members on each face. Appreciably better results will be obtained with cross braces if they are nailed at their intersection.

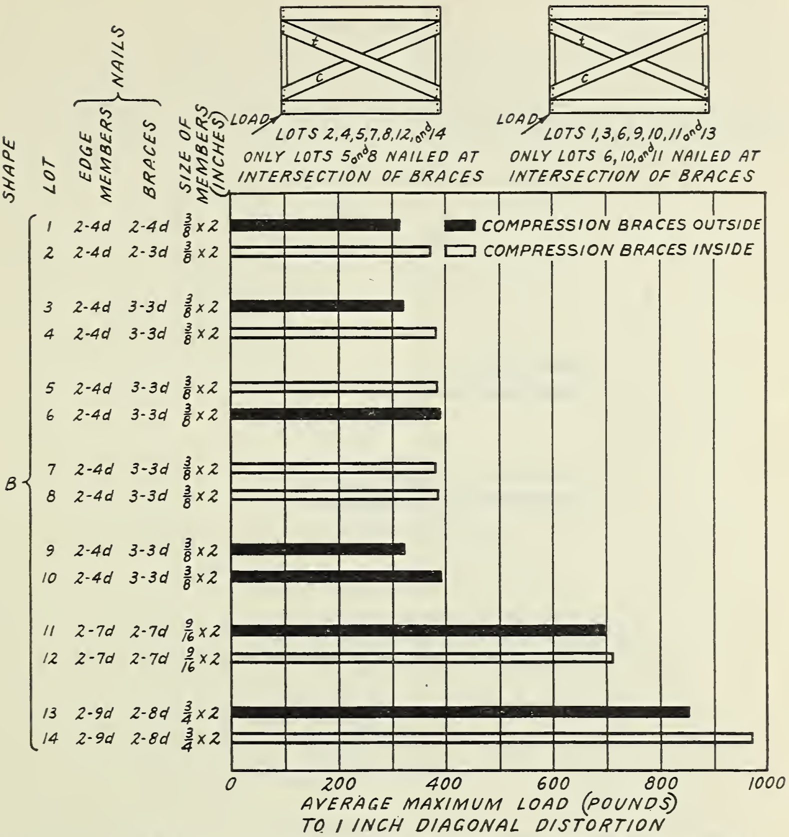

FIGURE 18.—Effect of relative positions of two braces one-half the thickness of the edge members crossed in each face and of nailing braces at intersection in each face. Tests made on ponderosa pine

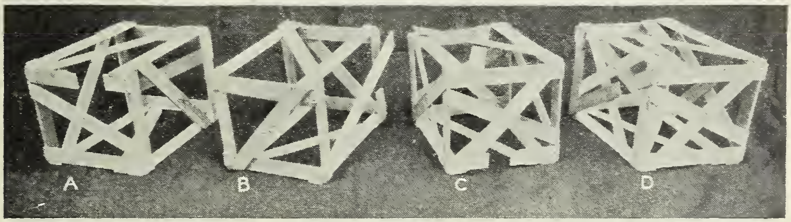

FIGURE 19.—Crates after test showing various methods of attaching braces: A, 6 braces of the same thickness as the edge members and nailed to the edges of the edge members; B, 6 braces of the same thickness as the edge members and nailed to the wide faces of the edge members; C, 12 braces one-half the thickness of the edge members having one brace in each face nailed to the edges and one brace nailed to the wide faces of the edge members; D, same as C except that braces were nailed to the intersection, constructions C and D having about the strength of A and nearly the same strength as B. The samples used for the determination of the moisture content of the crate material were taken from the rectangular cuts shown on the various members

EFFECT OF MANNER OF ATTACHING BRACES TO EDGE MEMBERS

Fully as important as the number and arrangement of the diagonals is the method of fastening them to the edge members of the crate. Any reinforcement or detail of construction that provides for better fastening of the braces will delay failure appreciably and result in increased strength and rigidity.

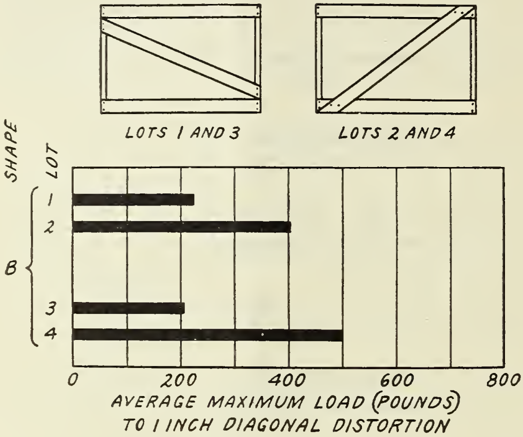

FIGURE 20.—Crates with one brace in each face nailed to the wide faces compared in strength with crates with similar braces nailed to the narrow faces of three-eighths by 2 inch edge members. Tests made on ponderosa pine crates with one three-eighths by 2 inch brace in each face nailed to the wide faces of three-eighths by 2 inch edge members and on similar crates with the braces nailed to the narrow faces of the edge members. Two 4-penny nails were used at each end of all members. The nails fastening the braces to the wide faces of the edge members were clinched

Two methods of fastening the diagonal braces other than the usual method of fastening them to the edges of the edge members were studied. One of these consisted in the use of reinforcing blocks nailed to the edge members near the crate corner so as to provide

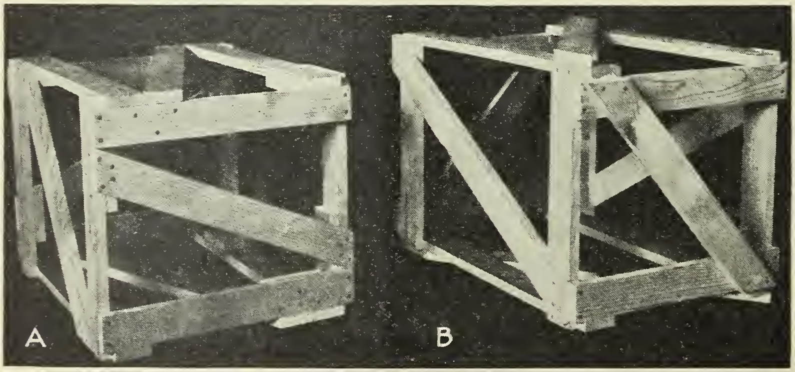

FIGURE 21.—Two methods of increasing the strength of crates: A, Reinforcing blocks at the ends of all braces; B, braces nailed to the wide faces of the edge members. Construction A gave about double the strength of crates of similar construction without blocks. Construction B gave about double the strength of crates with braces nailed to the edge of the edge members

an opportunity for additional nailing of the braces. (Fig. 21, A.) The other method consisted in nailing the braces to the wide faces of the edge members and clinching the nails. (Fig. 21, B.)

REINFORCING BLOCKS

Reinforcing blocks fastened to the crate edge members near the corners provide additional means of nailing for both edge members and diagonals, resulting in increased strength and rigidity, which is of considerable advantage in crating many commodities. Figure 22 shows the advantage of such reinforcement resulting from tests on ponderosa pine and western hemlock crates reinforced with blocks at

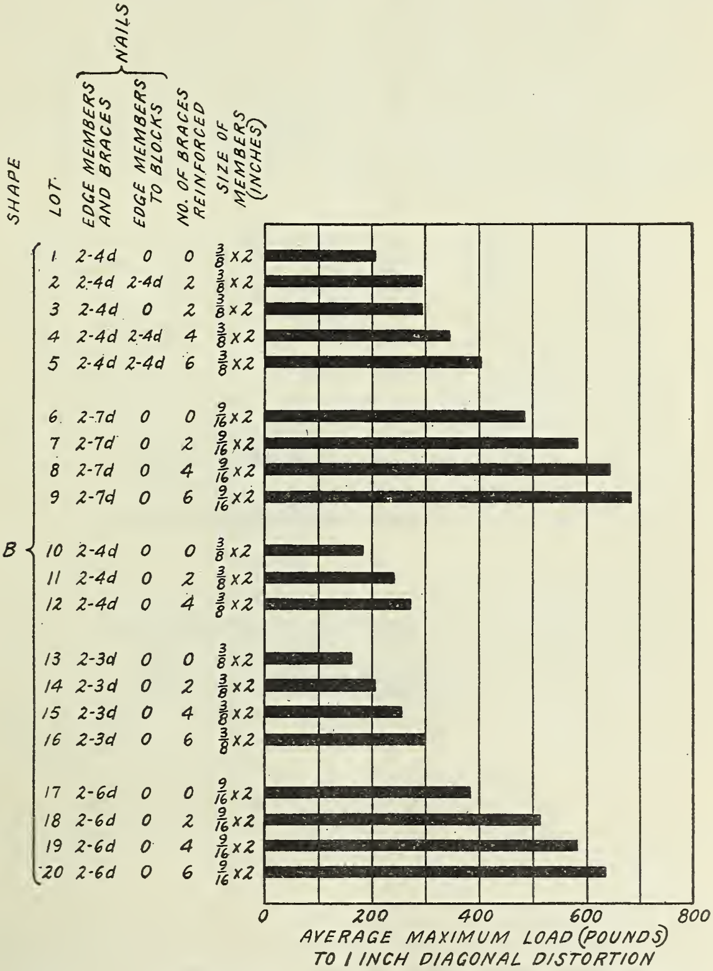

FIGURE 22.—The strength of a crate can be approximately doubled by the use of reinforcing blocks at the ends of all braces. The increase in strength is roughly proportional to the number of reinforcing blocks used. Tests made on crates having one brace in each face. Braces nailed to blocks with two nails at each end. Lots 1 to 9 were constructed of ponderosa pine. Lots 10 to 20 were of western hemlock

the ends of 2, 4, and 6 braces. The blocks were of the same thickness as the edge members and were nailed and clinched to the inside faces of the edge members at the ends of the braces. The increase in strength resulting from such reinforcement was roughly proportional to the number of braces reinforced. Reinforcing blocks at the ends of all braces (fig. 22, lot 5), gave from one and one-third to two times the strength of matched crates without blocks. (Fig. 22, lot 1.)

Where the commodity entirely fills the crate, it is, of course, impossible to use reinforcing blocks inside the crate, as was done in these tests. Under such conditions, it might prove desirable to attach blocks to the outer faces of the edge members. Blocks on the outside, however, would not be expected to be quite as efficient as blocks on the inside. Blocks on the outside of the crates would also require more space in storage and would tend to catch on obstructions in skidding along a platform or floor.

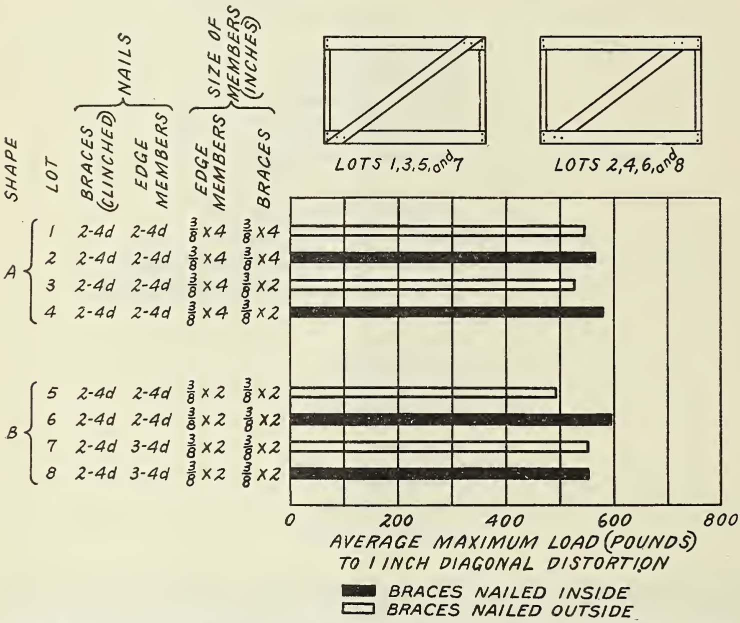

FIGURE 23.—Ponderosa pine crates with braces in each face nailed outside the wide faces of edge members compared in strength with crates having braces nailed inside the wide faces of edge members

If blocks are not inserted at the ends of all diagonals, then it is evident that the most important position for the blocks that are used is at the ends of the diagonals where failure is most likely to occur. (P. 5.)

NAILING BRACES TO WIDE FACES OF EDGE MEMBERS

Nailing the braces to the wide faces instead of to the narrow faces adds considerably to the strength and rigidity of a crate and under certain circumstances may prove desirable in order to avoid early splitting of the edge members. This method of attaching the braces resulted in crates in which the strength was approximately double that of crates in which the braces were nailed to the narrow faces. (Fig. 20.)

There are two ways in which the braces can be nailed to the flat faces of the edge members: They can be placed either inside or outside. Tests on crates of two shapes showed an average advantage of approximately 10 per cent for nailing the braces inside the edge members. (Fig. 23.) This small but consistent advantage is attributed to the fact that the three compression braces were favored by a bearing in the corners of the crate.

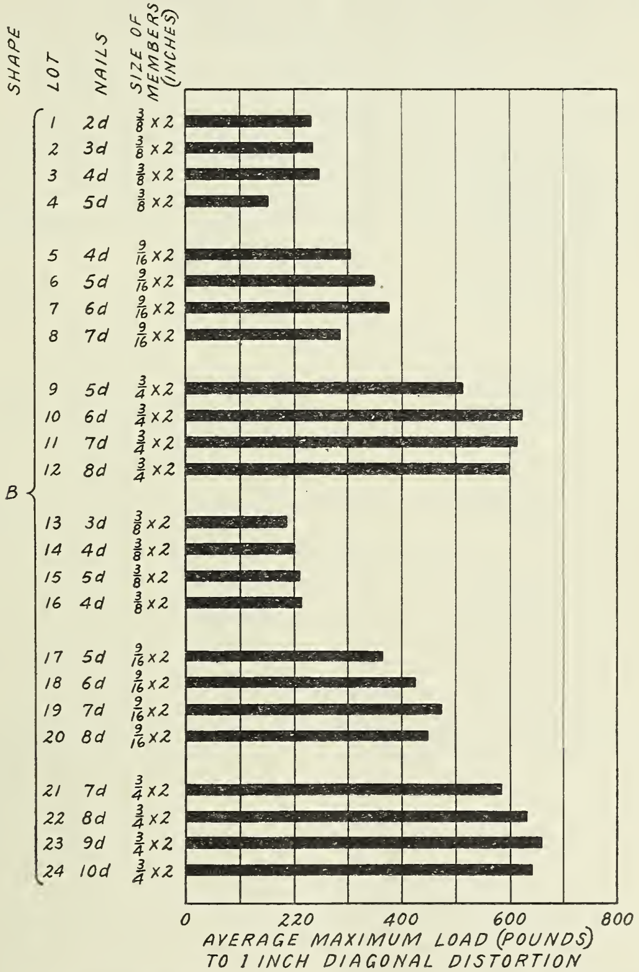

FIGURE 24.—Effect of nail size on the strength of crates having one brace in each face and two nails in each end of all members. Crates shown in lots 1 to 12 were made of western hemlock; lots 13 to 24 of ponderosa pine. Lot 16 differed from lot 14 in that three 3-penny nails fastened the braces

Further advantages in fastening the braces to the flat faces of the edge members when the braces are nailed inside are that there is no increase in the space occupied by the crate in stowing and that there is no difficulty in piling and skidding. Fastening the braces on the inside is, of course, only possible where the braces do not interfere with the proper packing of the commodity.

EFFECT OF VARYING NAIL SIZE

The discussion up to this point has dealt with design factors other than the nailing. The effect of varying the nail size in otherwise equivalent crates was to increase the strength with increase in nail size up to the point where driving the nails resulted in the splitting of the members. Any further increase in nail size caused a reduction in strength, as is shown graphically in Figure 24 for crates of western hemlock and ponderosa pine with three sizes of members. The results show that maximum efficiency was usually obtained with the nailing schedule given in Table 3. This schedule is also confirmed by other tests and observations of crates in service, and is therefore recommended for crates having all main members of the same thickness.

TABLE 3.—*Maximum size of cement-coated cooler or sinker nails for use in crates*

Classification of woods	Size of nails when thickness of edge members holding points of nails is—								
	3/8 inch or less	7/16 inch	1/2 inch	9/16 inch	5/8 inch	11/16 inch	3/4 inch	13/16 inch	7/8 inch
	Penny	*Penny*	*Penny*	*Penny*	*Penny*	*Penny*	*Penny*	*Penny*	*Penny*
Group 1	5	6	6	7	8	8	9	9	10
Group 2	4	5	6	6	7	7	8	8	9
Group 3	4	5	5	6	6	7	7	8	8
Group 4	4	4	5	5	5	6	6	7	8

GROUP 1

Aspen.
Aspen, largetooth.
Basswood.
Butternut.
Buckeye, yellow.
Cedar, northern white.
Cedar, Port Orford.
Cedar, western red.
Chestnut.
Cottonwood, black.
Cottonwood, eastern.
Cypress, southern.
Fir, alpine.
Fir, balsam.
Fir, California red.
Fir, lowland white.
Fir, noble.
Fir, silver.
Fir, white.
Magnolia, cucumber.
Magnolia, evergreen.
Pine, jack.
Pine, lodgepole.
Pine, northern white.
Pine, Norway.
Pine, ponderosa.
Pine, sugar.
Pine, western white.
Poplar, yellow.
Redwood.
Spruce, Engelmann.
Spruce, red.
Spruce, Sitka.
Spruce, white.
Willow, black.
Willow, western black.

GROUP 2

Fir, Douglas.
Hemlock, eastern.
Hemlock, western.
Larch, western.
Pine, loblolly.
Pine, longleaf.
Pine, mountain.
Pine, pitch.
Pine, pond.
Pine, shortleaf.
Pine, slash.
Tamarack.

GROUP 3

Ash, black.
Ash, pumpkin.
Elm, American.
Gum, black.
Gum, red.
Gum, tupelo.
Maple, silver.
Sycamore.

GROUP 4

Ash, green.
Ash, white.
Beech.
Birch, sweet.
Birch, yellow.
Elm, rock.
Elm, slippery.
Hackberry.
Hickory.
Maple, black.
Maple, sugar.
Oak, red.
Oak, white.

CONCLUSIONS

The following conclusions are deduced from tests at the Forest Products Laboratory on a total of 550 crates of ponderosa pine, western hemlock, and Sitka spruce:

The point of failure in diagonally braced crates made of lumber free from injurious defects is usually at the fastening of the diagonals to the edge members.

The forces in the various crate faces tending to cause the splitting of the edge members to which diagonal braces are nailed are approximately proportional to the lengths of the edge members to which the braces are not nailed.

A long edge member will fail more readily by splitting at the fastening of the diagonal braces than a short edge member when the braces are nailed to the narrow faces of the edge members.

Increase in width or thickness of all the crate members generally results in a substantial increase in strength, provided the nailing is in accordance with the recommended nailing schedule. (P. 24.)

The best practice is to use rectangular crate members as nearly square as practicable.

Crates of the sizes tested, having six diagonal braces one-half the thickness of the edge members, are nearly as strong and rigid as similar crates having braces the same thickness as the edge members.

The difference in strength between crates having the long edge members of the smallest faces placed outside the short edge members and crates having the short edge members of the smallest faces placed outside the long edge members is so small that the controlling factor should be convenience and protection of the faces of the commodity rather than increased strength of the crate.

Whether diagonal braces are in tension or compression under load makes no difference in the ultimate strength of a crate, provided the braces are thick enough to develop the full strength of the nailed joint without bending. Under normal conditions this would be at a ratio of $\frac{60}{1}$.

The strength and rigidity of a crate increases with each diagonal brace added, the maximum increase occurring with the addition of the sixth brace.

Unless the commodity is known to be able to take torsional stress or is so suspended in the crate that it will not twist with distortion of the crate, all faces of the crate should be braced.

Crates having 12 diagonal braces (2 crossed in each face) one-half the thickness of the edge members showed approximately one and one-half times the strength of crates with 6 diagonal braces of the same thickness as the edge members nailed to the edges of the edge members.

In crates with two braces one-half the thickness of the edge members crossed in each face, nailing the braces at their intersection resulted in slightly increasing the strength of the crates.

In crates having one diagonal brace in each face, nailing reinforcing blocks to the edge members at the ends of all six diagonals resulted in an average increase in strength of approximately two-thirds, as compared with the strength of unreinforced crates.

For crates with six diagonal braces, nailing the braces to the wide faces of the edge members and clinching the nails resulted in the crates having more than twice the strength of crates in which the braces were nailed to the edges of the edge members.

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